



ADEPT

Adaptable Deployable Entry & Placement Technology (ADEPT)

Presentation for Outer Planet Aerocapture meeting

Paul Wercinski, Project Manager

October 7, 2015

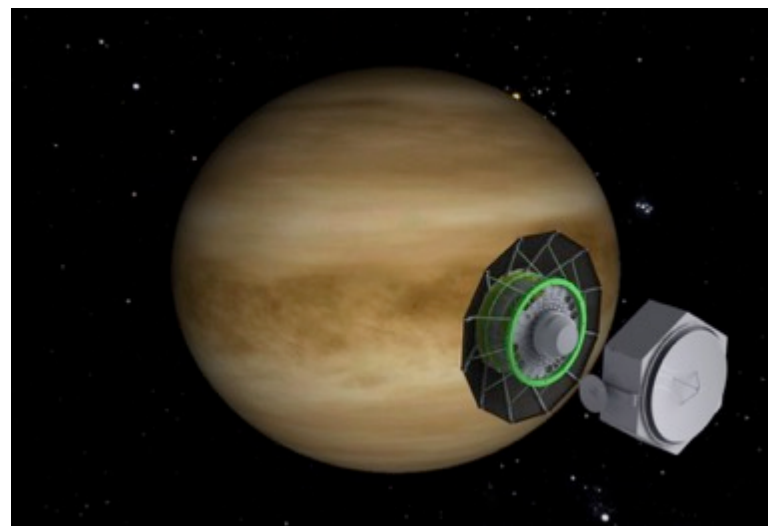


What is ADEPT?

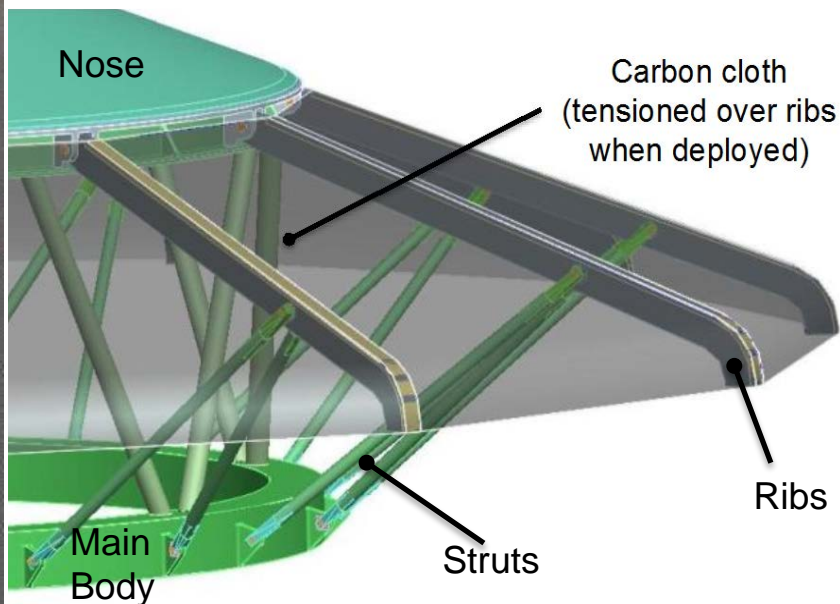
(Adaptive Deployable Entry & Placement Technology)



Earth departure



Arrival at Destination



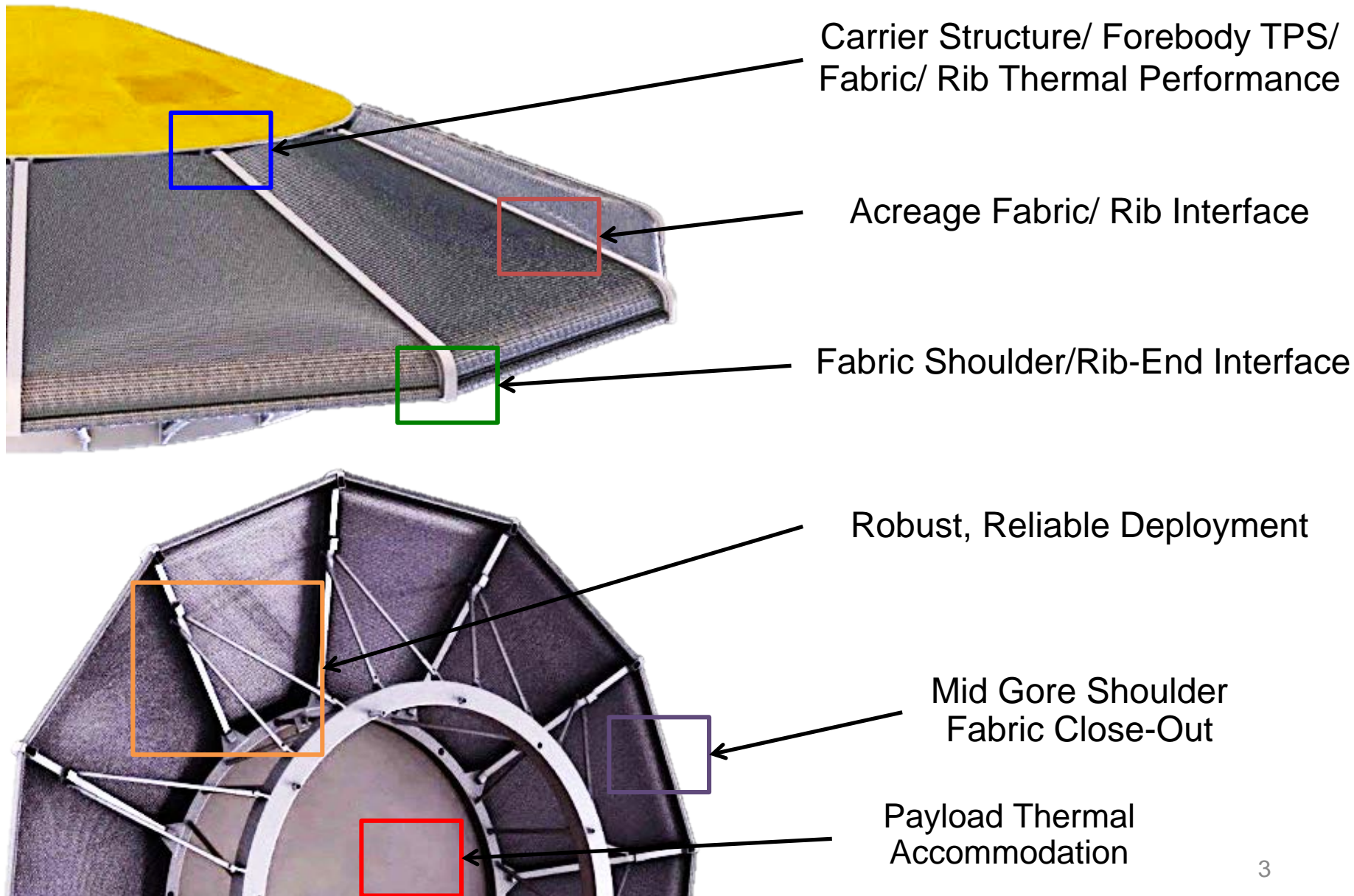
ADEPT is an atmospheric entry *architecture* that is Game Changing for missions to most planetary bodies with atmospheres.

- Provides a benign deceleration and thermal environment to the payload.
- Stowed inside the launch vehicle shroud and deployed in space prior to entry.
- Structural ribs support 3D woven carbon fabric to generate drag and withstand high heating.

Key Technical Functional Challenge Areas



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ADEPT Project Overview



➤ ADEPT FY12-FY13

- ◆ Funded under STMD Game Changing Development Program
- ◆ Focus on 6m Venus DRM (Delivery of 1000kg lander with peak decel < 30 g's)
- ◆ Carbon fabric arc-jet tested 100-240 W/cm².
- ◆ Successful demonstration of 2m Ground Test Article



Carbon Fabric arcjet testing (2012)

➤ ADEPT FY14

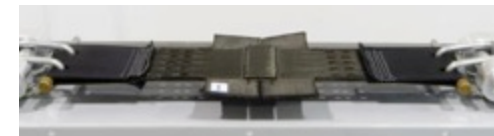
- ◆ Early year focus continued 6m Venus, Demonstration carbon-fabric stitched joint
- ◆ Mid-year budget reduction forced development goal re-plan - > 1m scale
 - Cost effective approach for key system-level demonstrations



2m Ground Test Article (2013)

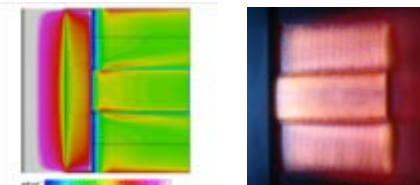
➤ ADEPT FY15

- ◆ Continuation of 'FTE-only' project status
- ◆ Focus on 0.7m aero-loads wind tunnel test, 0.35m SPRITE pathfinder arcjet test
- ◆ Perform risk mitigation and formulation efforts in anticipation of FY16 0.7m sounding rocket flight test



➤ ADEPT FY16

- ◆ ADEPT currently limited to 4 FTE. Tech development limited



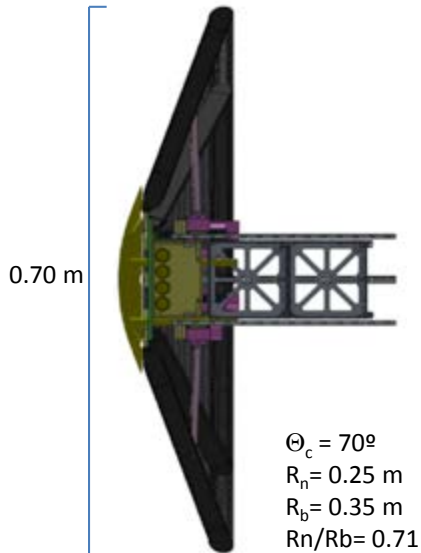
Fabric Joint Design Testing (2014)

ADEPT Development Roadmap (1m scale)

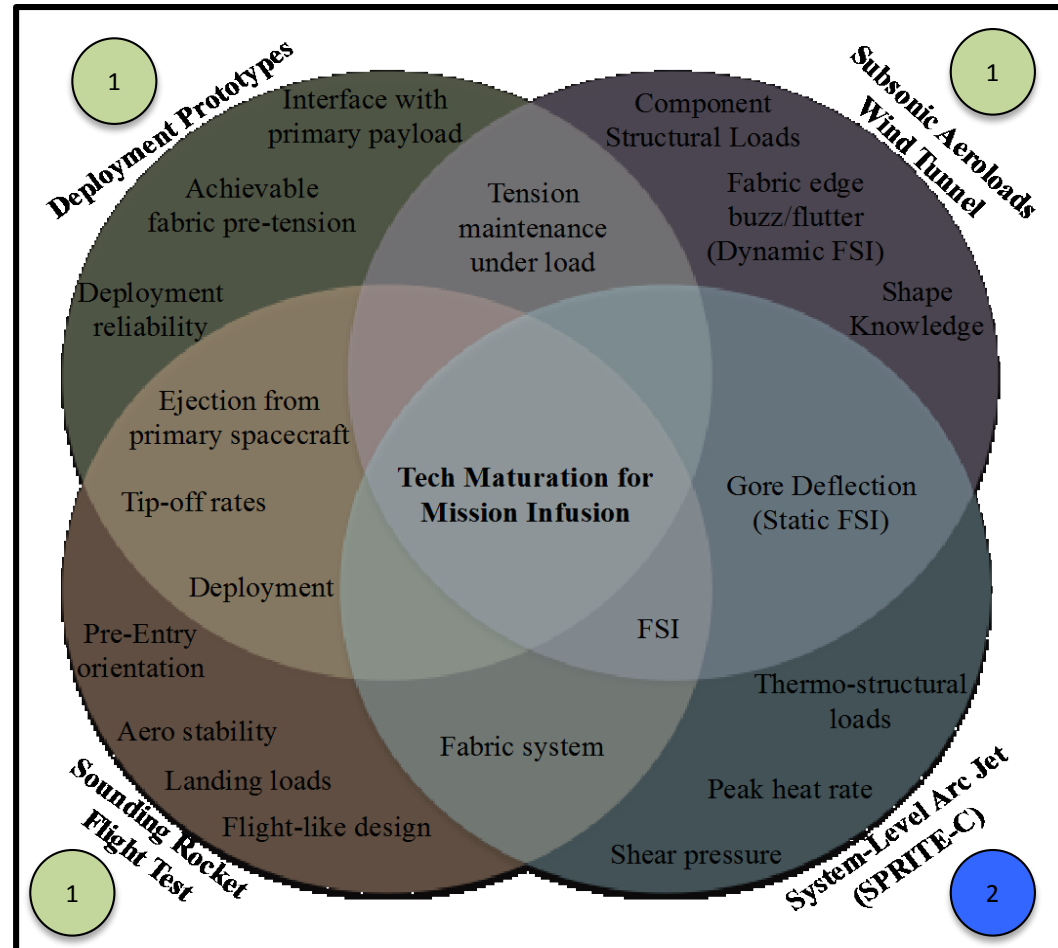


- Strategy addresses technical challenges with four system-level tests
- Common geometric features between design reference missions (DRMs), ground tests, and flight test provide ground-to-flight traceability

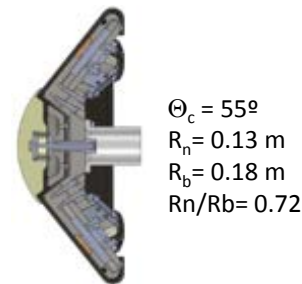
Config. 1



Primary geometric features of deployment prototypes, subsonic aeroloads wind tunnel test articles, sounding rocket flight test, and some DRMs



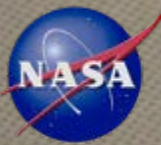
Config. 2



Primary geometric features of system-level arc jet tests (SPRITE-C)

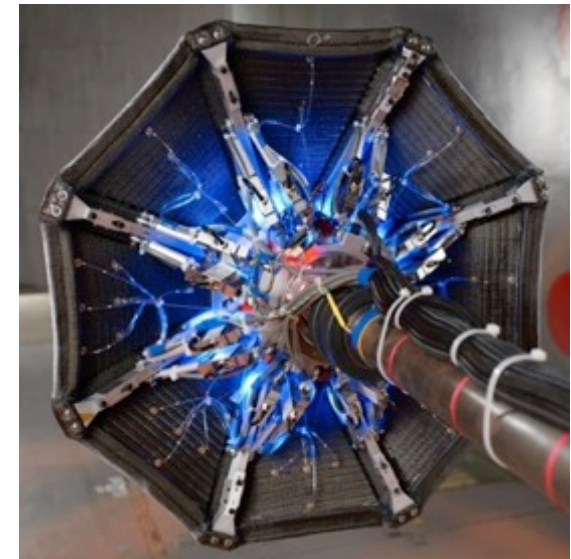


Aeroloads Test Overview and Objectives



- Testing was completed in seven business days at the US Army's 7x10 Foot Wind Tunnel located at NASA Ames (27-Apr to 5-May 2015)
- Shared funding was provided through NASA STMD GCDP ADEPT program (FY15) and a NASA Ames Center Innovation Fund Award (FY14)

Test Objective	Instrumentation
<p>Obtain static deflected shape and pressure distributions while varying pre-tension* at dynamic pressures and angles of attack relevant to Nano-ADEPT entry conditions at Earth, Mars, and Venus.</p> <p>*Tension in the carbon fabric is caused by two sources: "pre-tension" resulting from the mechanical deployment of ADEPT prior to atmospheric entry and additional tension resulting from the aerodynamic load during entry</p>	<p>Photogrammetry; String potentiometers; Outer Mold Line (OML) static pressure taps</p>
<p>Observe dynamic aeroelastic behavior (buzz/flutter) if it occurs as a function of pre-tension, dynamic pressure, and angle of attack.</p>	<p>High speed video; Strut load cells</p>
<p>Obtain aerodynamic forces and moments as a function of pre-tension, dynamic pressure, and angle of attack.</p>	<p>Internal balance</p>



- Flight-like carbon fabric skirt includes key features such as carbon yarn stitching and seam resin infusion
- Central nut moves all struts simultaneously to pre-determined positions to induce a known pre-tension in fabric



Video Highlights from 7x10 Test



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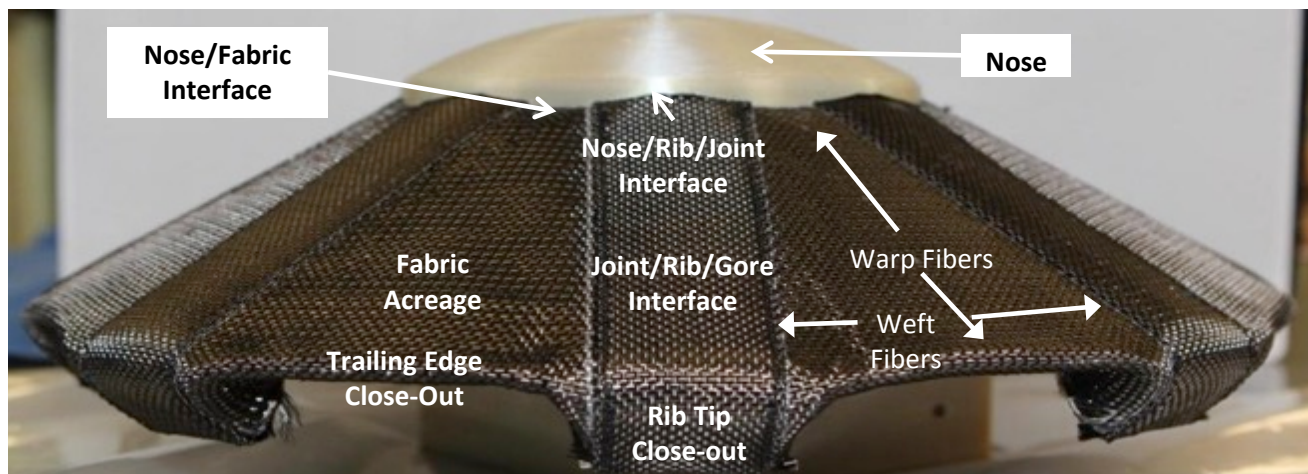
SPRITE-C Arcjet System Level Tests (FY15)

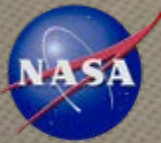
- **OBJECTIVE:** Characterize response of system level design features under relevant aerothermal environments.
 - Utilize flight-like interface designs
(*Nose/fabric, Nose/Joint, Joint/Rib, Trailing Edge Close-out*)
- **APPROACH:** A relevant scale, 360 degree test article allows for testing of multiple design features
 - Heavily instrumented test article
 - Mars DRM heating conditions (50-150 W/cm²)
- **IMPACT:**



SPRITE-C Prototype Test Article Fit check in the Ames Interaction Heating Facility

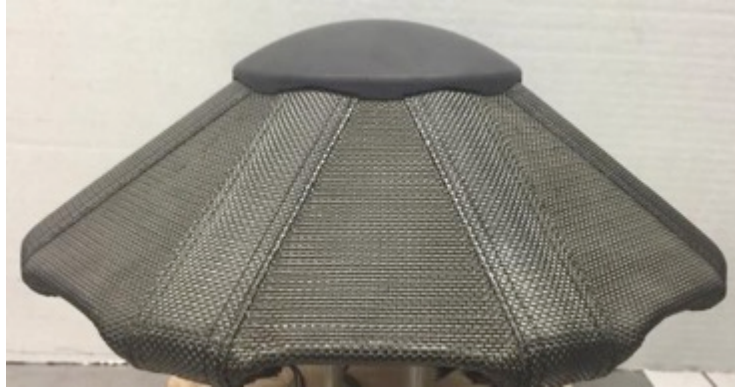
Efficient and cost-effective methodology to achieve system-level aerothermal performance in relevant environments



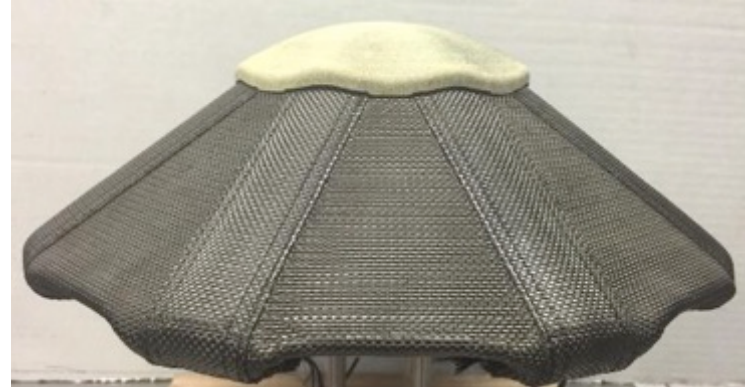


SPRITE-C Arcjet Test Preparations

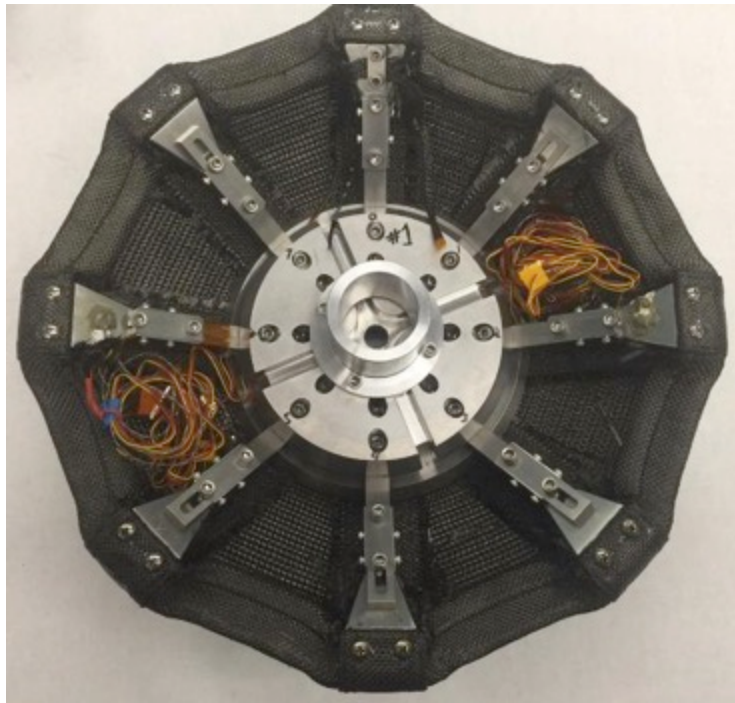
Graphite Nose Cap



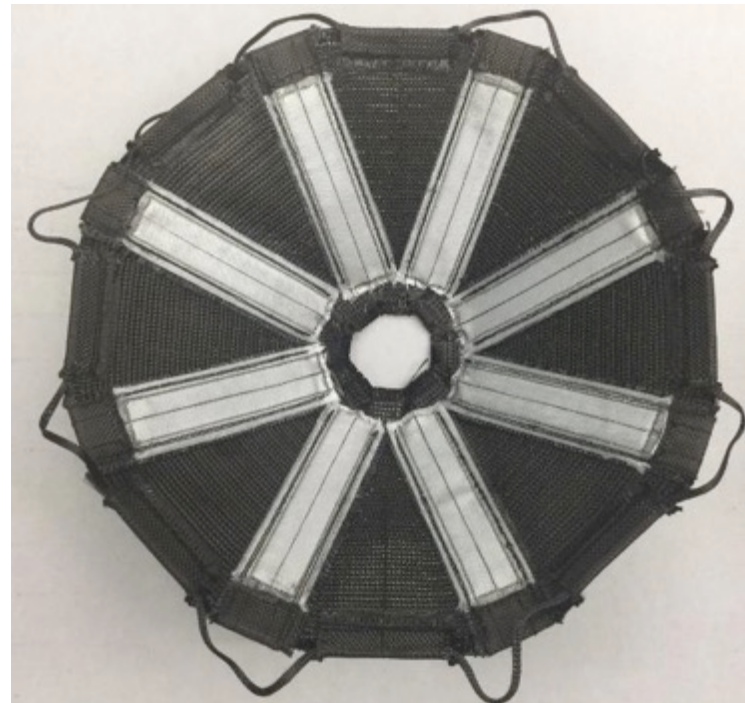
Conformal PICA Nose Cap



Embedded Instrumentation



Insulating Fabric Skirt Design



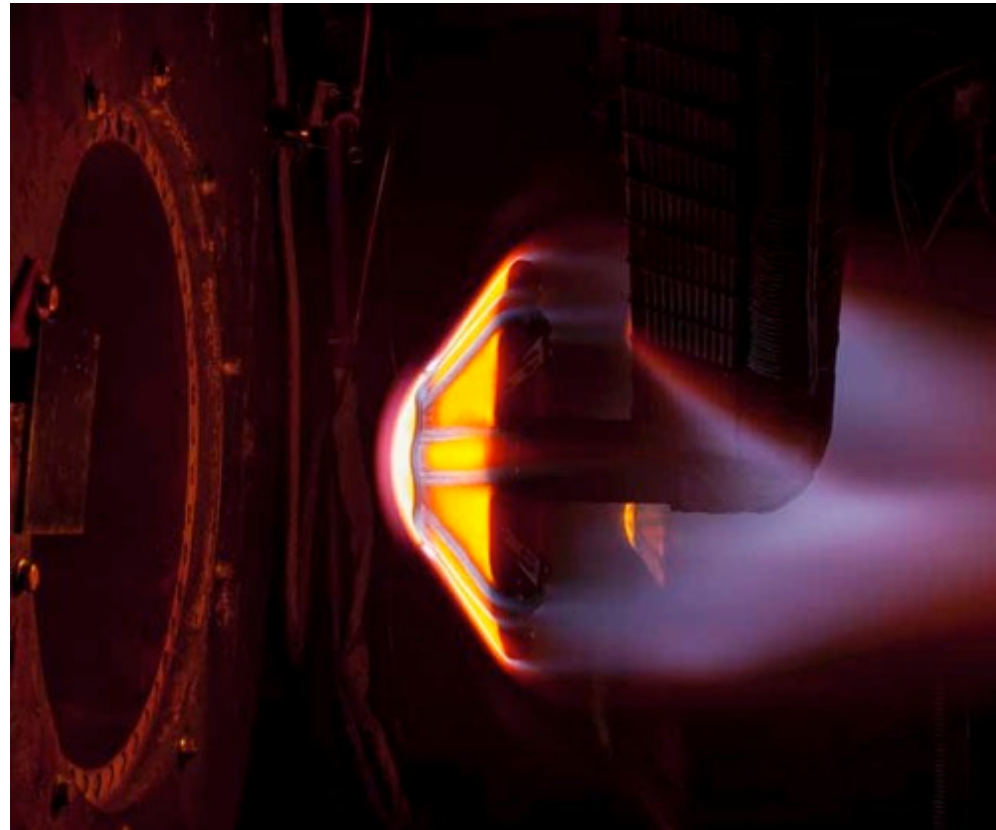
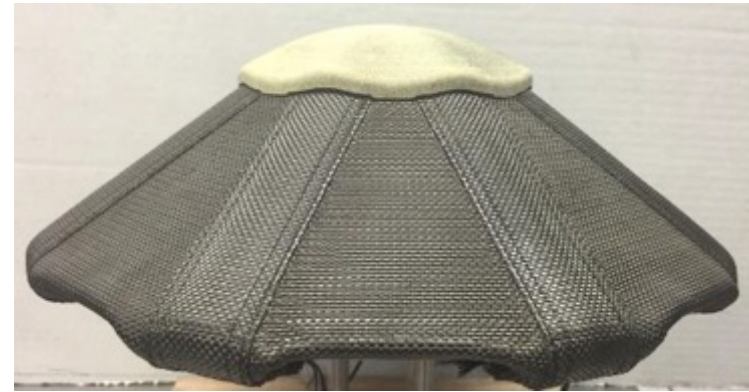


SPRITE-C Pathfinder Arcjet Test Article #2

C-PICA Nose, 6 Layer, Phenolic Resin joint



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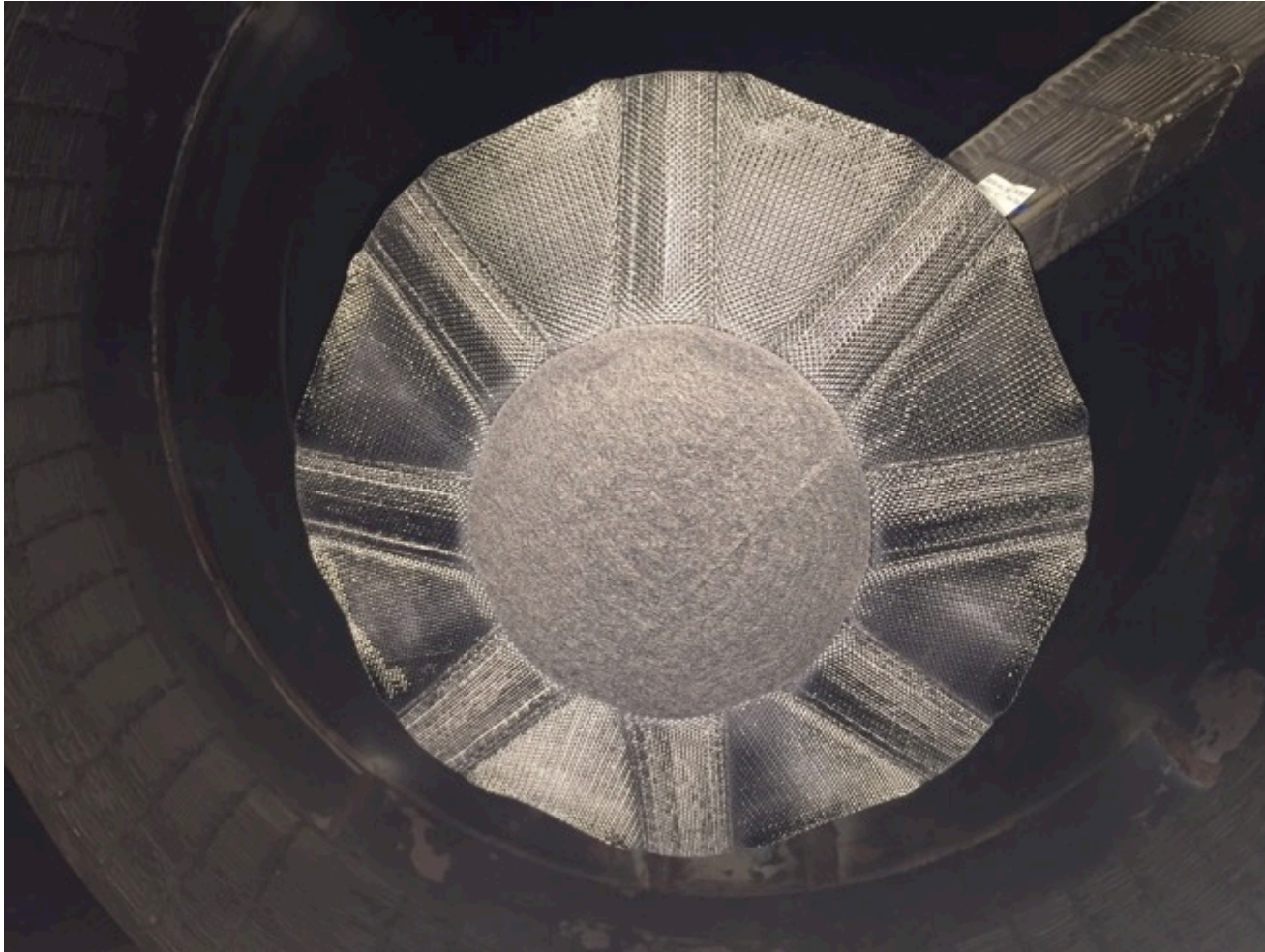


SPRITE-C Pathfinder Arcjet Test Article #2

Post-Test Image



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SPRITE-C Arcjet Test Matrix and Conditions



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Environment Predictions

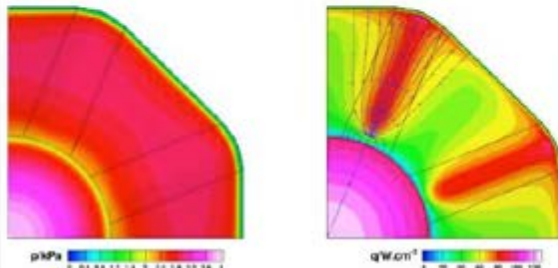
Condition 1

IHF 21.5-in nozzle, 10" from nozzle exit plane

$I_{arc} = 2000$ A

$m_{air} = 200$ g/s, $m_{air+} = 55$ g/s, $m_{Ar} = 26$ g/s

$P_{arc} = 240$ kPa



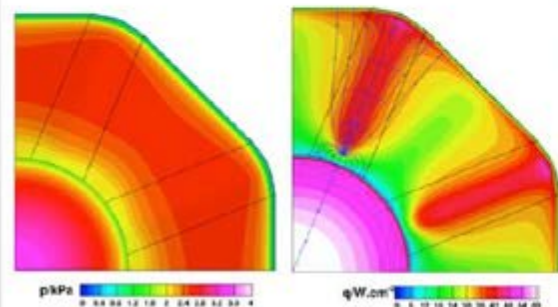
Condition 2

IHF 21.5-in nozzle, 10" from nozzle exit plane

$I_{arc} = 2200$ A

$m_{air} = 110$ g/s, $m_{air+} = 160$ g/s, $m_{Ar} = 30$ g/s

$P_{arc} = 193$ kPa



Run Matrix

Run	Condition	Test Article/ Calibration Run	Sting	Stag Pt q_w (W/cm ²)	Stag Pt Prs (kPa)	Duration (sec)
1	1	4" Hemi Calorimeter	Overhead	245	4.2	-
		SPRITE-C #1 Spherical Graphite Nose w/ Phenolic infused joints	East	124	3.9	60
		SPRITE-C #2 Blended C-PICA Nose w/ Phenolic infused joints	West	124	3.9	40
2	2	4" Hemi Calorimeter	Overhead	125	3.4	-
		SPRITE-C #3 Spherical Graphite Nose w/ various resin infused joints	East	63	3.4	60
		SPRITE-C #2 (Re-run) Blended C-PICA Nose w/ Phenolic infused joints	West	63	3.4	40
3	1,2	4" Hemi Calorimeter	Overhead	Cond 1 & 2	-	-
		9 mm Pitot Probe	East	Cond 1 & 2	-	-
		SPRITE-C #4 Spherical Graphite Nose w/ various resin infused joints, using insulated 4- layer skirt	West	63	3.4	40



Proposed Sounding Rocket (Mach 3) Flight Test



- **OBJECTIVE:**

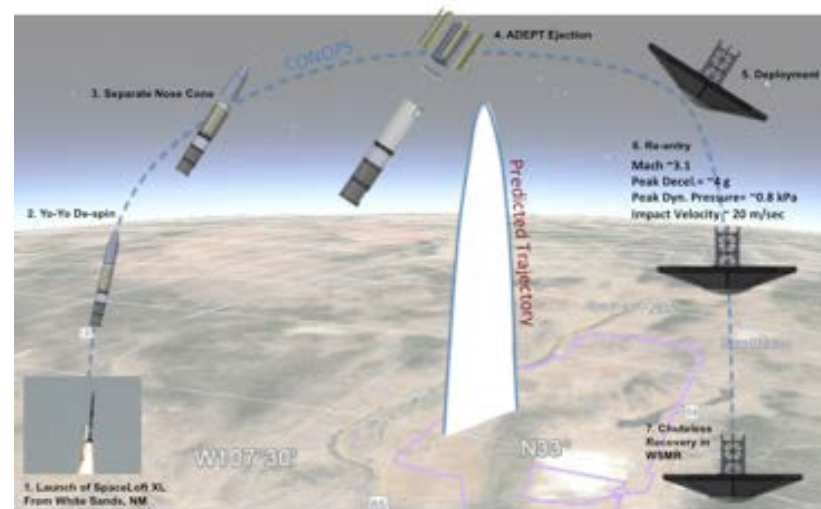
- Demonstrate LV separation and exo-atmospheric deployment.
- Characterize aerodynamic performance from supersonic to subsonic flight regimes. Tech First for 70deg sphere cone shape!

- **APPROACH:** Demonstrate ADEPT 1 m class system flight performance. TAYF: FAYT

- Low cost approach leveraging multiple programs within STMD portfolio. (*GCD, SBIR, Flight Opportunities, Center Innovation Fund*)

- **IMPACT:**

- Provide flight test experience for ADEPT configuration.
- Critical first step in integrated flight hardware experience to apply to larger scale applications and analytical modeling
- Design capable of delivering ~ 5 kg of cube-sat like payloads



Sounding Rocket Flight Test ConOps:

Achieves ~115 km altitude, followed by LV separation and exo-atmospheric deployment. Upon re-entry, ADEPT achieves $M=3.1$.

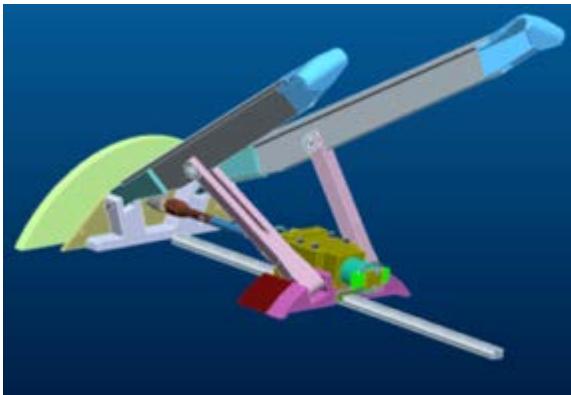
- ✓ Approved (July 2014) as directed payload from Flight Opportunities Program
- ✓ Developed two-stage spring-based passive deployment approach



Deployment Prototype Development



ADEPT in UP Aero Payload Canister
(Folded fabric not shown)

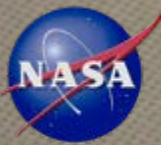


1/4 Model Proof of Concept

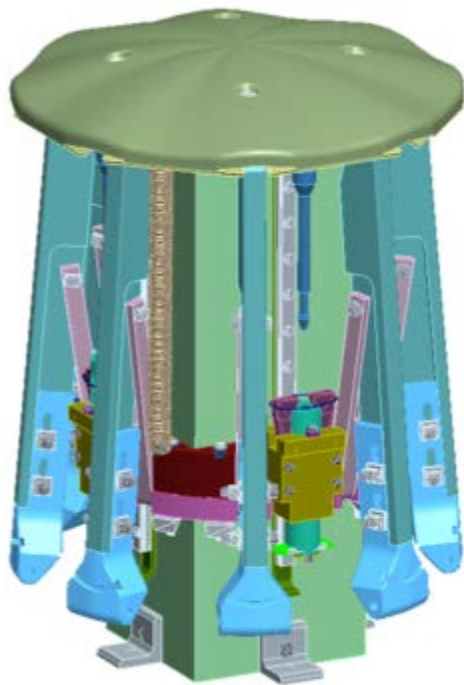
- **Spring actuated deployment proposed for sounding rocket configuration**
 - Fast operation for SR mission timeline
 - Simple (No motors, batteries or control system)
- **Challenges include:**
 - Tight packaging between ADEPT “cubesat payload” and available diameter within sounding rocket
 - Long stroke with high force required at end of stroke to tension fabric (contrary to typical spring behavior)
 - Nose cap movement needed to prevent wrinkling of fabric at nose cap interface
 - Accommodating fabric interfaces and folding into tightly packaged stowed state
- **Approach:**
 - 1/4 model designed and built for proof of concept, design debug, bench testing & identifying improvements
 - Full deployment prototype designed & built based on findings from 1/4 model debug & test
 - Deployment prototype successfully tested for function
 - Plan to use prototype for testing with modified carbon fabric skirt and for separation from SR canister
 - Lessons learned will be applied to SR flight unit design



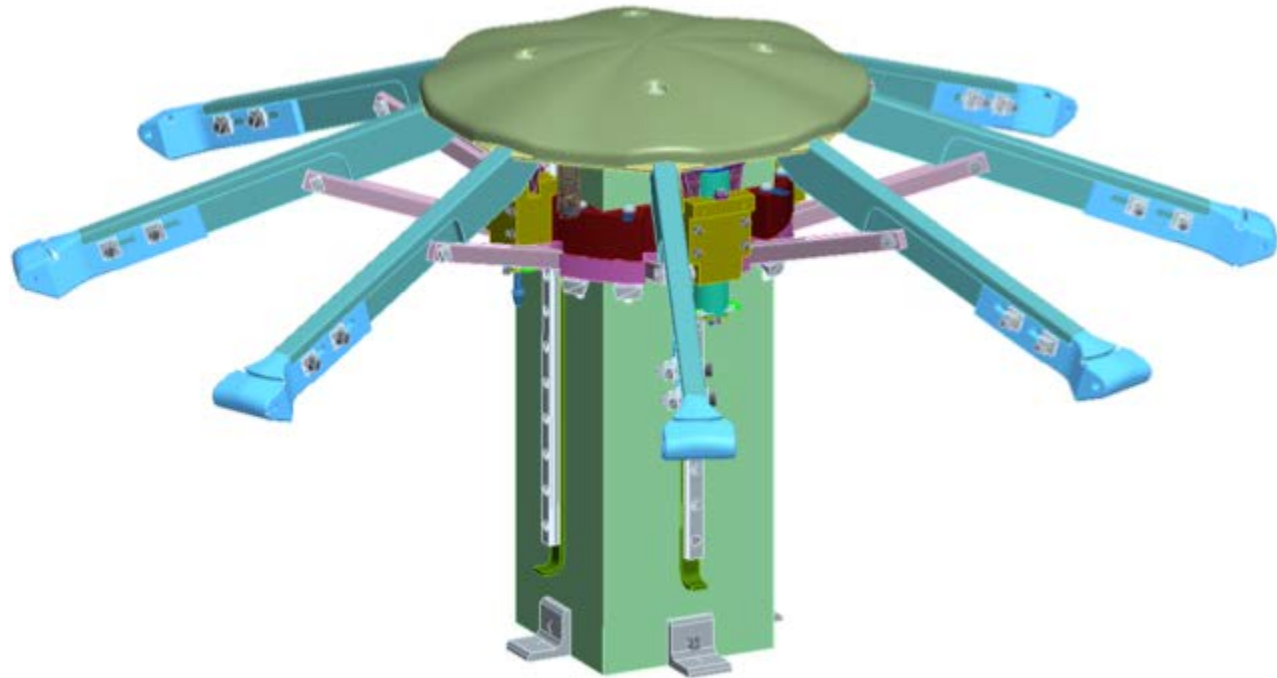
Deployment Prototype Design



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CAD Model - Stowed State



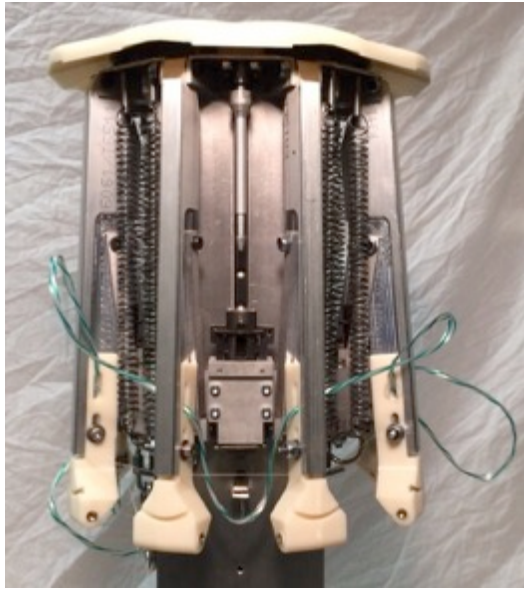
CAD Model - Deployed State



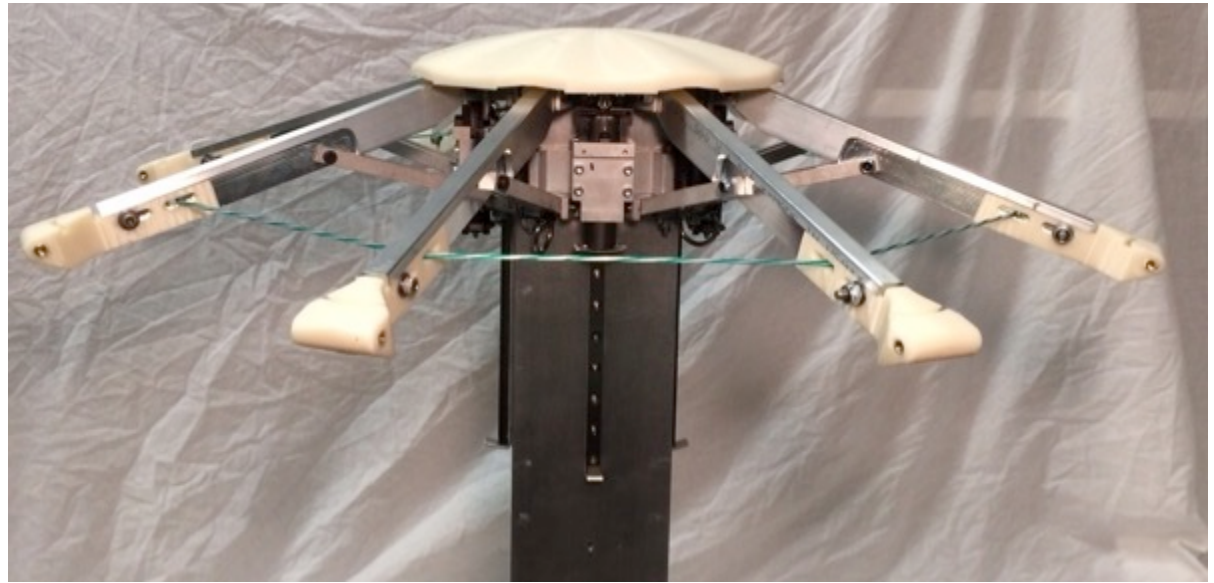
Deployment Prototype Hardware



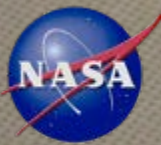
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Stowed State



Deployed State



Deployment Prototype

- Deployment Prototype Features:
 - Full-scale for sounding rocket configuration
 - Target fabric pre-tension of 10 lb/in (per flight requirements)
 - Designed for 4-layer carbon fabric
 - Initial testing with surrogate fabric (multi-layer laminate material simulating thickness & stiffness)
 - Additional testing planned with updated carbon fabric skirt
 - Two-stage deployment mechanism triggers high-force springs near end of travel to tension fabric
 - Linear guide rails (4) maintain even deployment
 - Nose cap movement is integrated with 2nd stage of deployment mechanism
 - Pulls nose cap down against fabric at end of travel to eliminate wrinkles and/or gaps
 - End-of-travel latches lock ADEPT in the deployed state

- Deployment Prototype Deliverables
 - ✓ Deployment prototype hardware has been fabricated and assembled
 - ✓ Deployment prototype has demonstrated consistent deployment function

➤ **SEE DEPLOYMENT VIDEO ON NEXT SLIDE**





Deployment Prototype Video

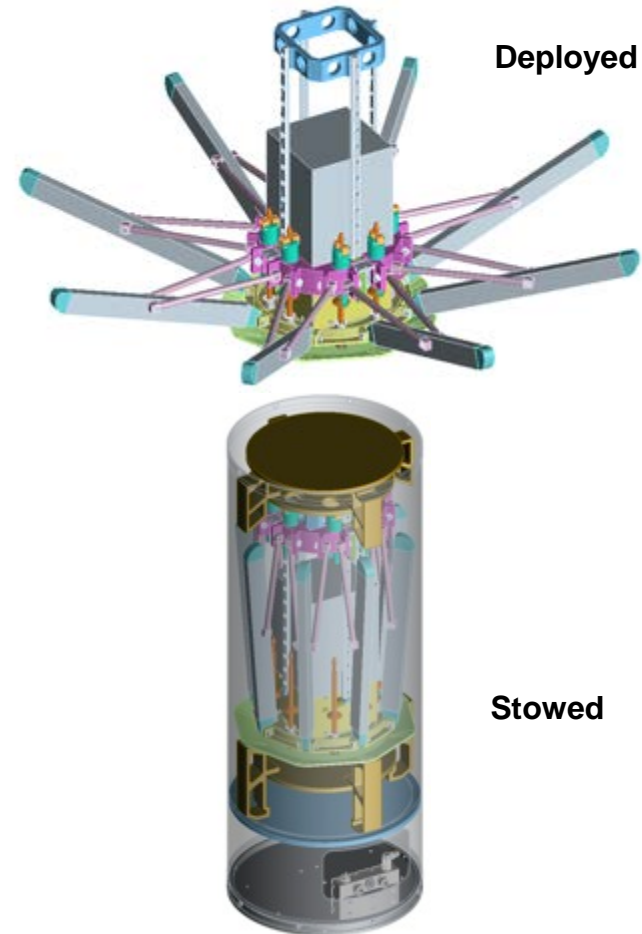
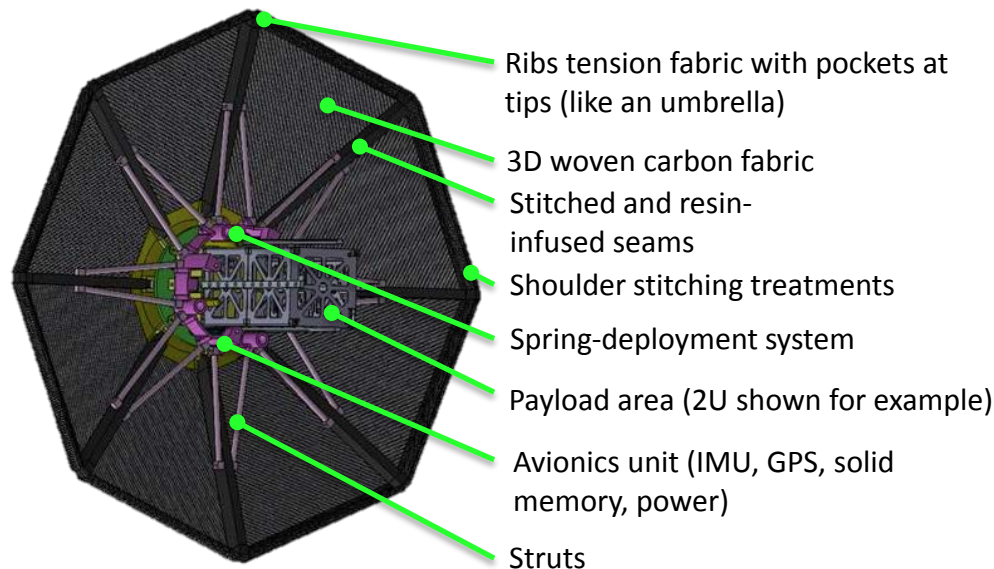


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Sounding Rocket Flight Test Planning (FY15)

- Sounding Rocket Deployment Prototype Design:
 - Carbon fabric skirts assessed for SR stowage compatibility
 - Deployment prototype demonstration in September

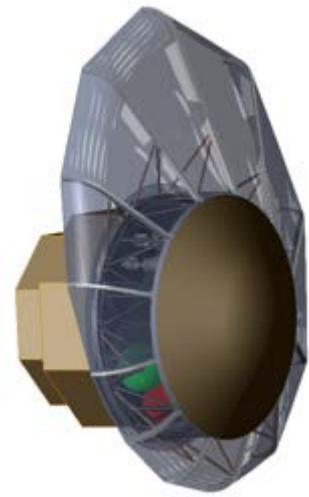
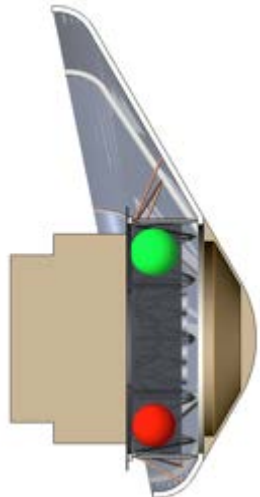
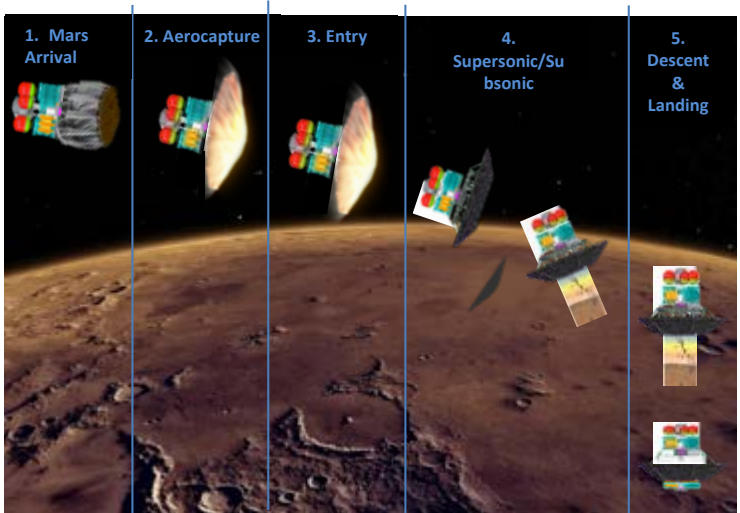


- Initiated planning discussions with Flight Opportunities Program (FOP) and Sounding rocket provider (UP Aerospace)
- Proposed ADEPT FY16 SR flight test
 - Similar con-ops as IRVE-II which flew in 2009
 - <\$4M total budget, this is not a TDM!

Sounding rocket payload mock-up:
Stowed and deployed 0.7m configuration compatible with UP Aerospace payload canister geometry

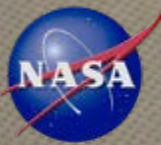


ADEPT for Mars EDL Pathfinder Study



- Dual-Pulse ADEPT Decelerator (Aerocapture and EDL from Mars orbit)
 - ADEPT remains deployed in Mars orbit post-aerocapture, ready for EDL from orbit
- Lifting, asymmetric shape (AFE-like, ACRV shape)
 - Generate L/D 0.2-0.3 without requiring significant offset CG requirements on Payload
 - Assume OML shape remains fixed (static) during hypersonic deceleration
 - Guided trajectory methodology (lift-vector control) TBD, RCS roll control probably lowest risk approach
- Transition to SRP and Terminal Descent
 - Assume retention of ADEPT deployable through initiation of Supersonic Retro Propulsion
 - Vehicle AoA at SRP initiation?, Need to re-trim?, Rigid nose accommodation of SRP nozzles?
 - Ribs can be 'inverted' near landing touch-down to accommodate payload egress
- Other Considerations
 - ADEPT deployed and functionality verified in Earth orbit, prior to Departure

ADEPT



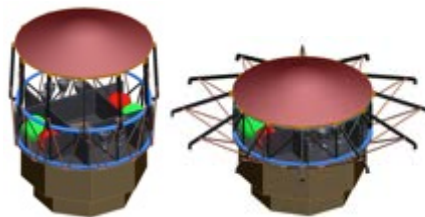
16m ADEPT Concept Configuration Matrix

NAME	CLASS	GEOMETRY	RIBS	STRUTS	DESCRIPTION
SC-01	Symmetric	70° Sphere-Cone	1-Piece (12X)	1-Piece	Aft ring translates forward for deployment
SC-02	Symmetric	70° Sphere-Cone	1-Piece (12X)	1-Piece	Forward ring translates aft for deployment
SC-03	Symmetric	70° Sphere-Cone	Articulated (12X)	1-Piece	Ribs fold forward over nose cap for stowage
AC-01	Asymmetric	60° Sphere-Cone	1-Piece (12X)	1-Piece	AFE mimic: 60° sphere-cone w/ 80.7° trailing edge
AC-02	Asymmetric	Ellipsoid	1-Piece (16X)	1-Piece	ACVe mimic: blended ellipsoid

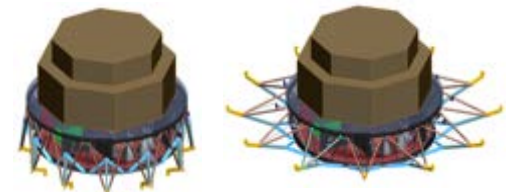
Current Baseline



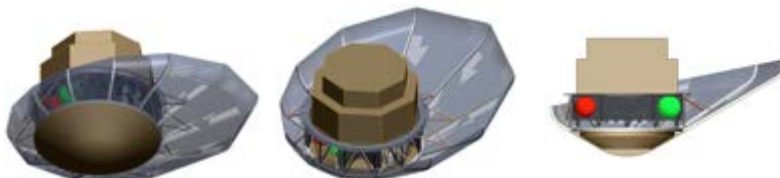
SC-01



SC-02



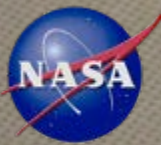
SC-03



AC-01



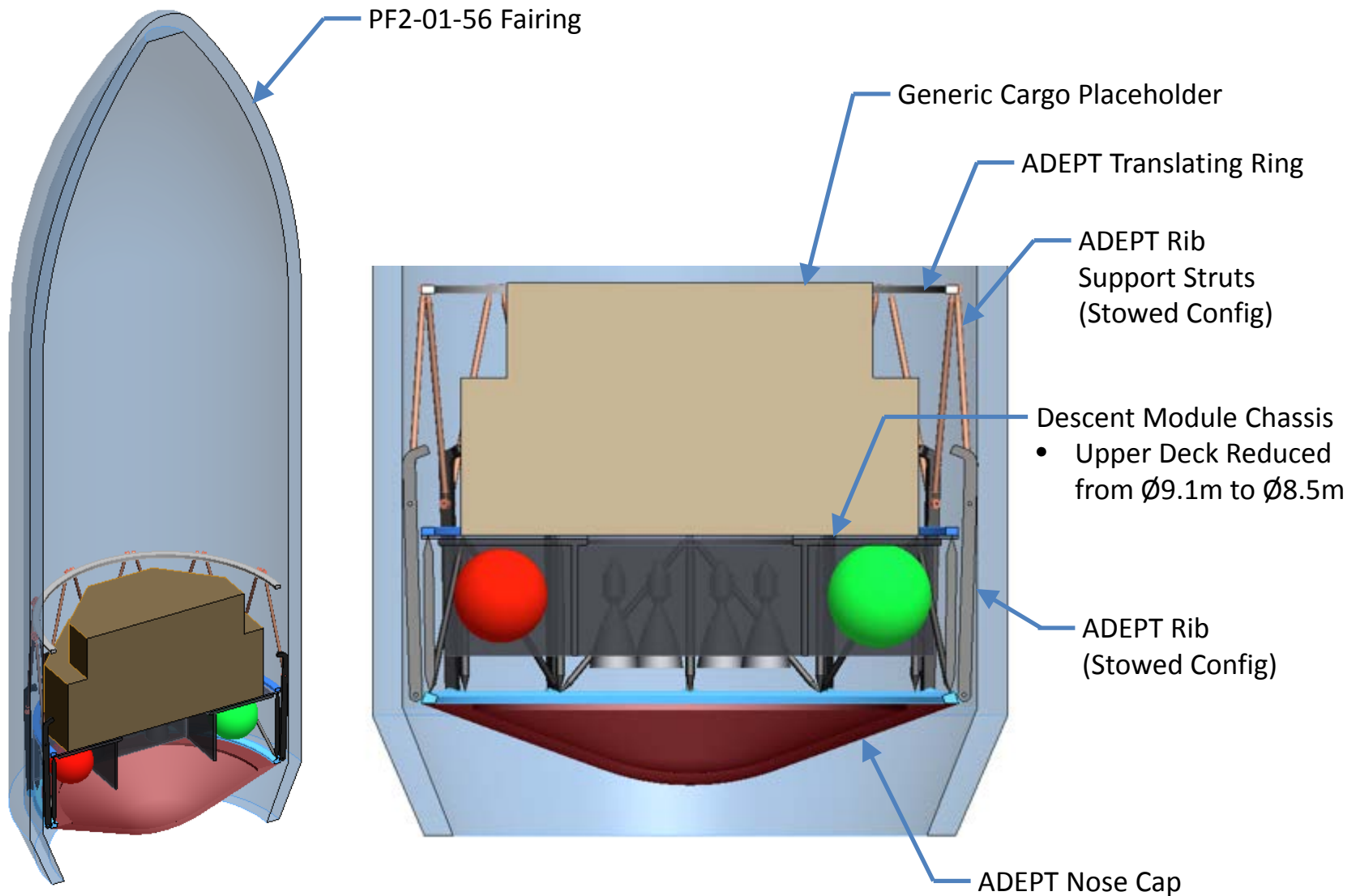
AC-02



ADEPT SC-01 Launch Configuration

Rigid Rib & Struts-Translating Ring

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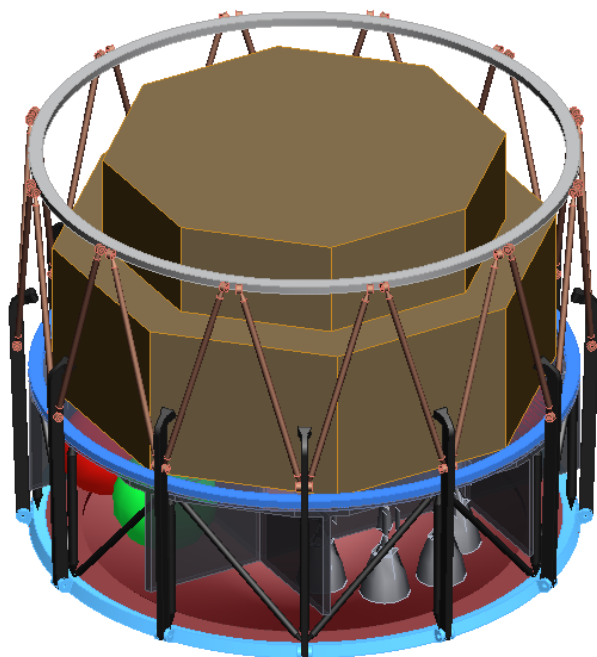




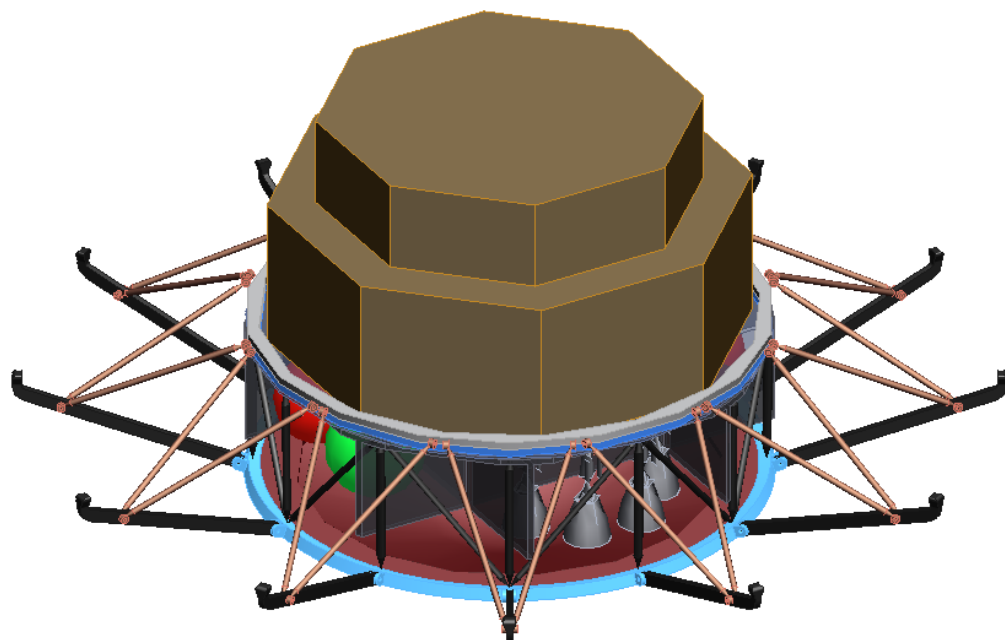
ADEPT-SC-01

Rigid Rib & Struts-Translating Ring

ADEPT



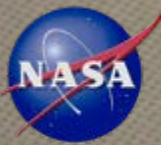
ADEPT Stowed Configuration



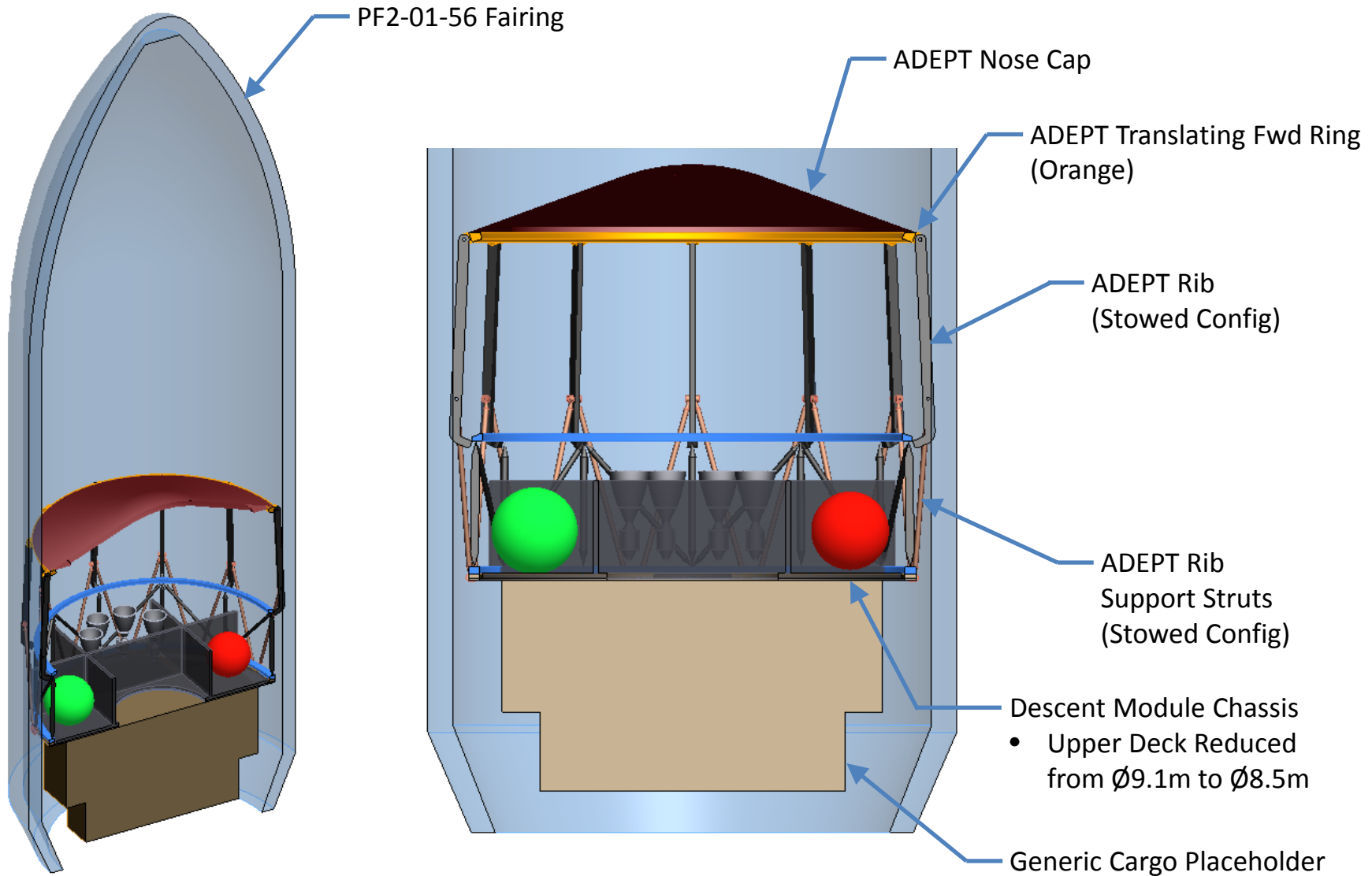
ADEPT Deployed Configuration

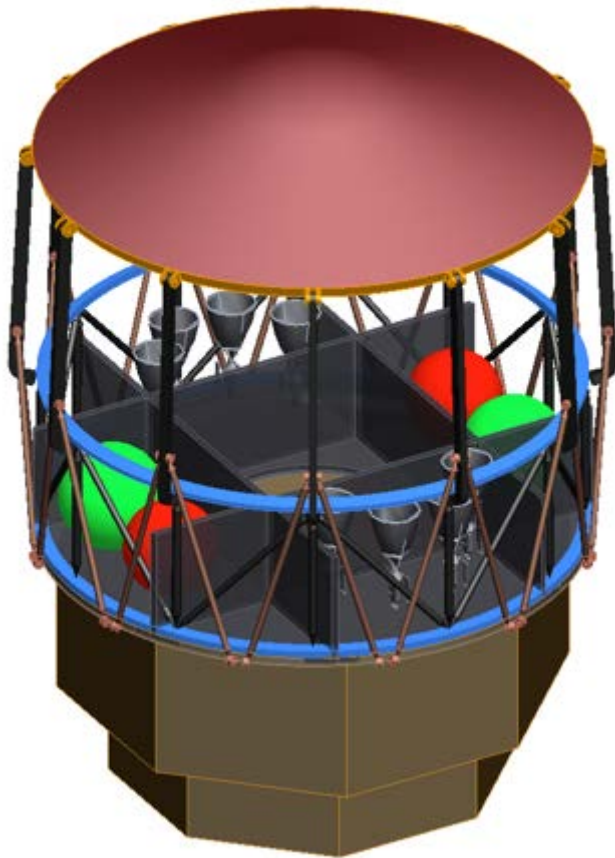


ADEPT SC-02 Launch Configuration

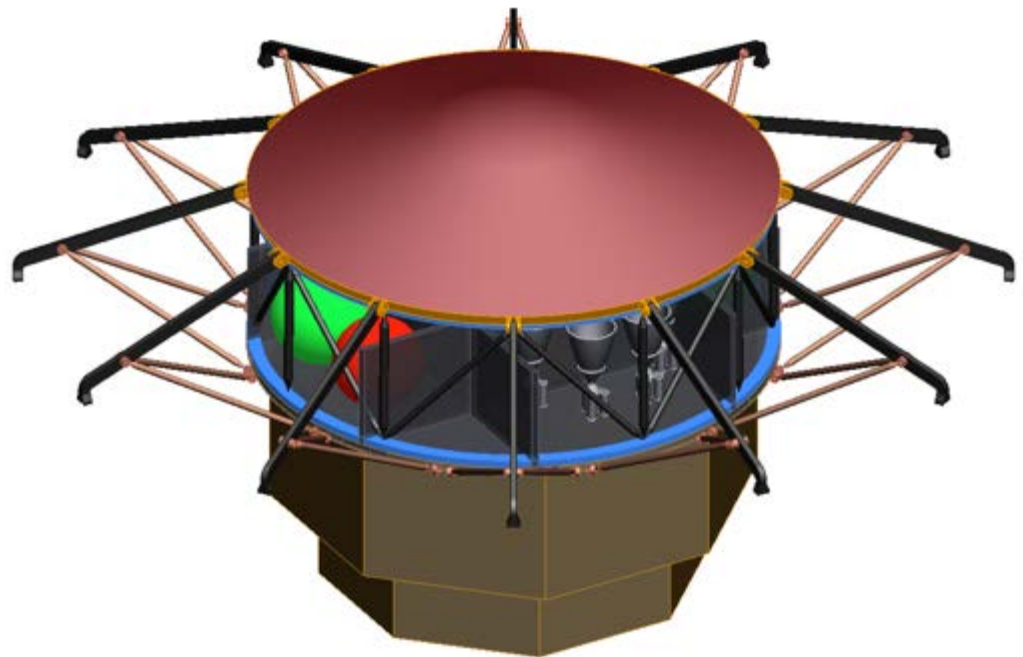


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ADEPT Stowed Configuration



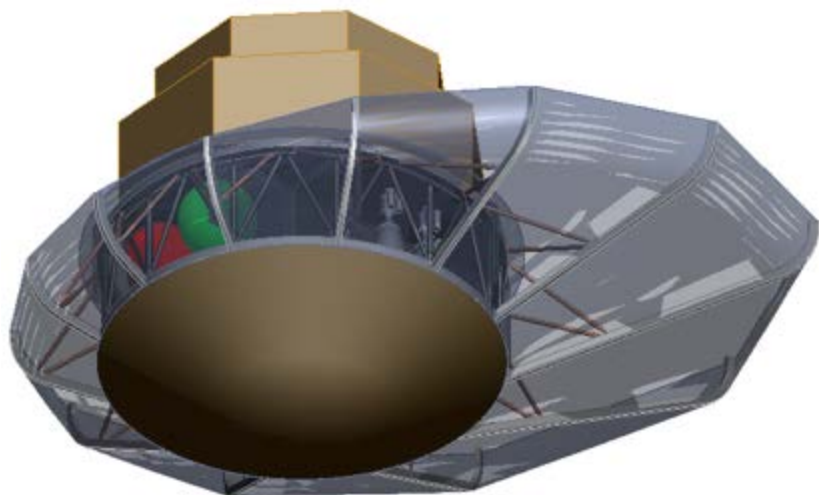
ADEPT Deployed Configuration



ADEPT AC-01

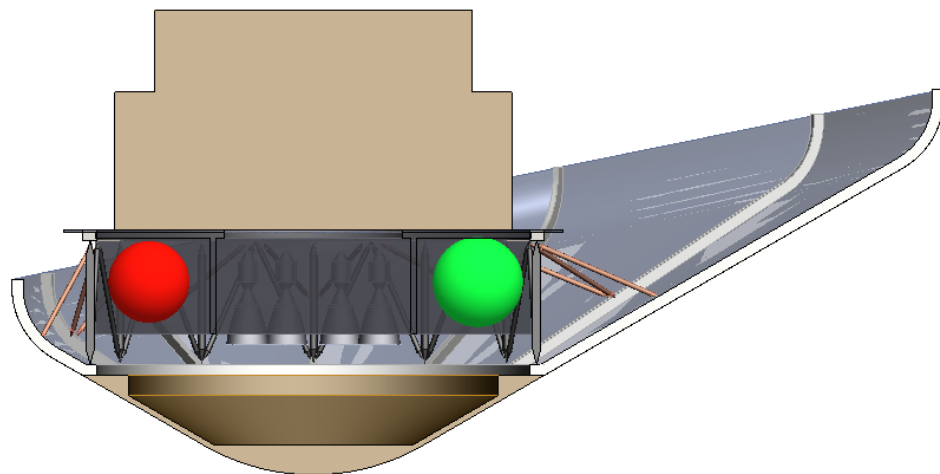
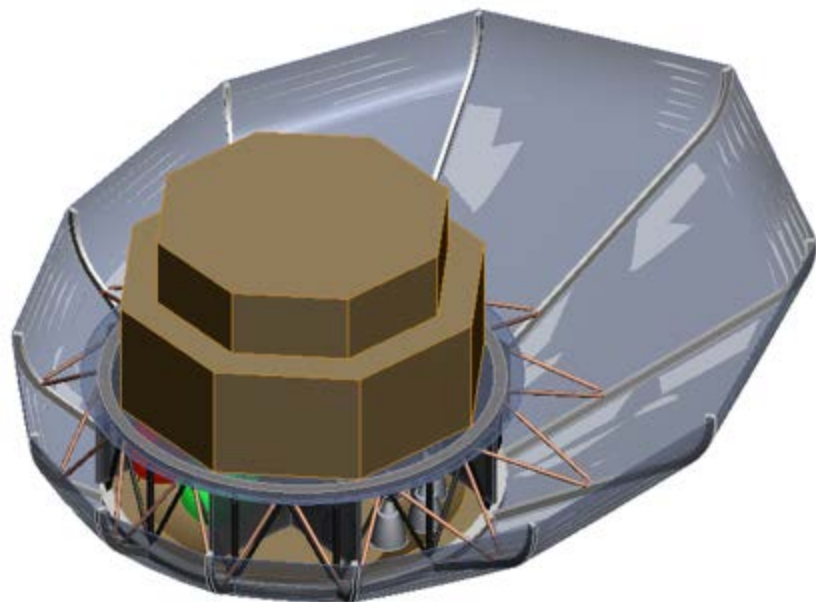


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ADEPT AFE Mimic Configuration:

- 60° offset cone (see early/mid-90s studies)
- Concept shown is highly notional
 - Stowage & deployment schemes TBD



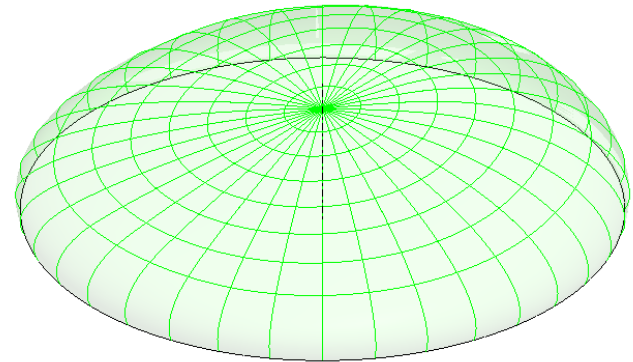
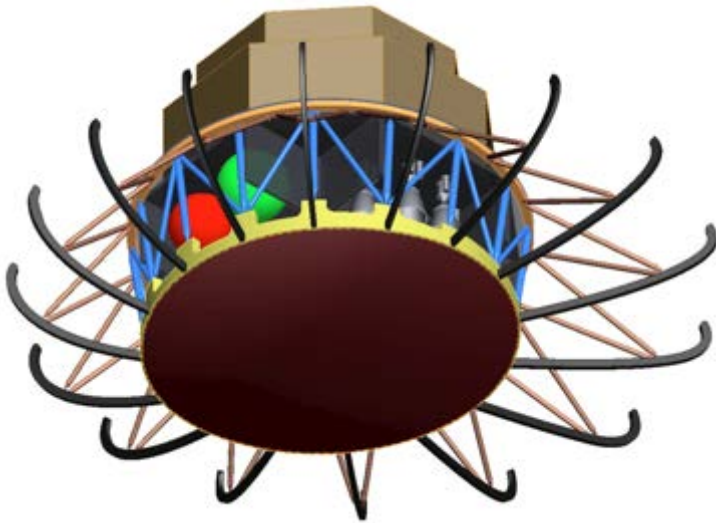


ADEPT AC-02

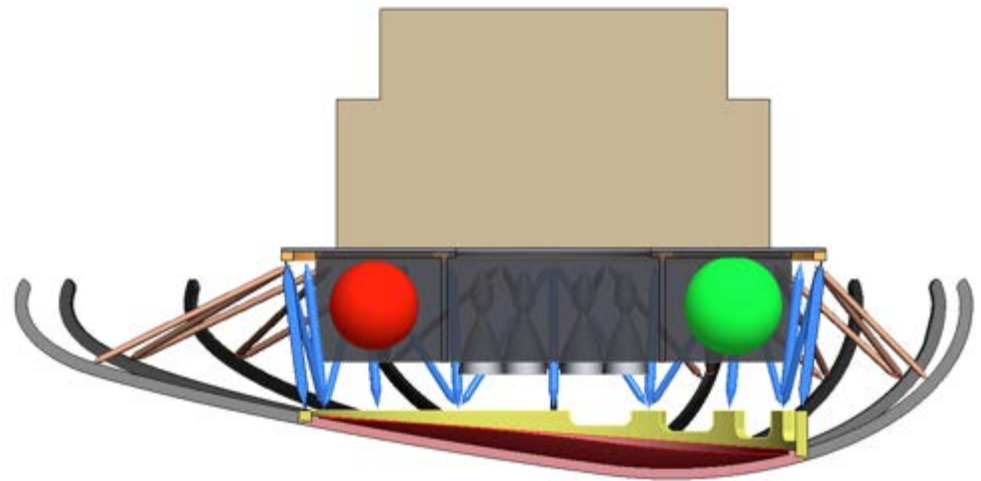
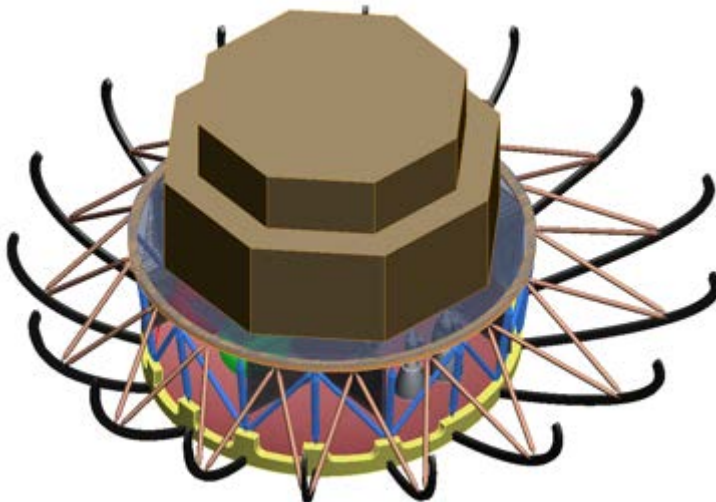
ACVe Shape stable through Supersonic

ADEPT ACV Mimic Configuration:

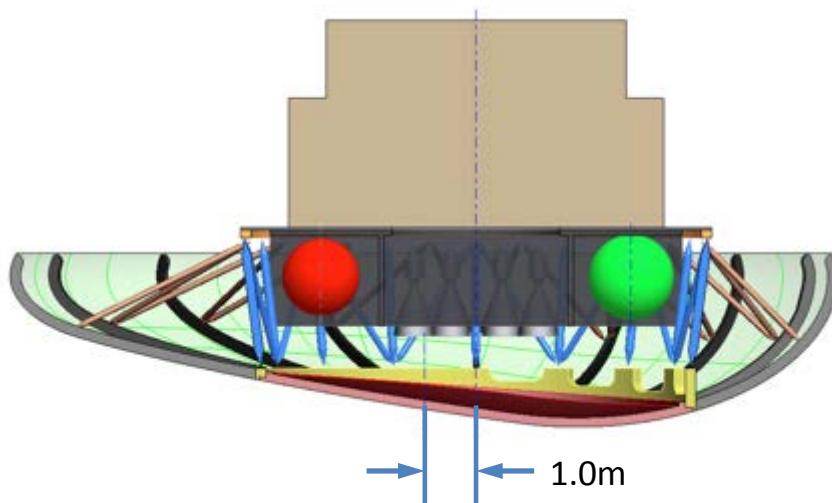
- 1m MDM-ADEPT centerline offset shown



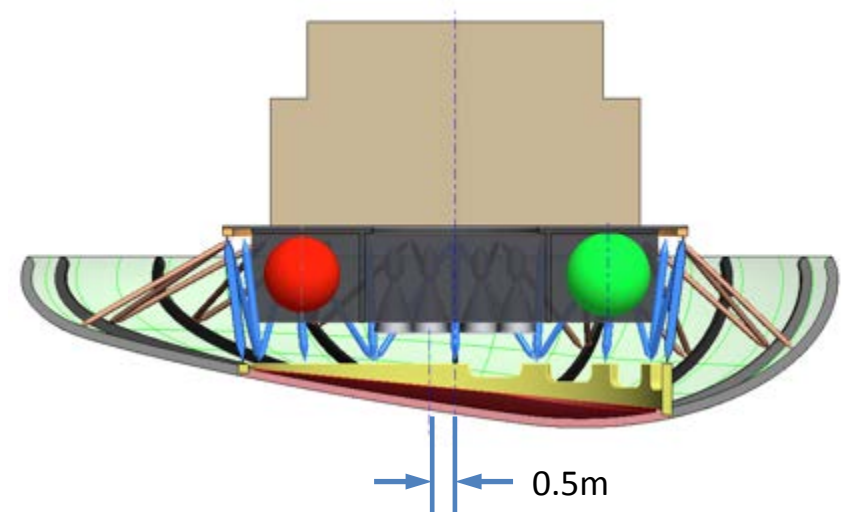
ACV OML Geometry (Reference)



ADEPT ACVe Concept



ADEPT ACVe 1.0m c/l Offset



ADEPT ACVe 0.5m c/l Offset

Extent of centerline (c/l) offset will be set by aerodynamic stability characteristics and by L/D requirements.

- Likely that c/l offset will be less than 0.5m